The milk yield of dams and its relation to direct and maternal genetic components of weaning weight in beef cattle

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Abstract

Cow milk yield is a critical component for the growth of the calves in the preweaning period. The genetic correlation between direct weaning weight and milk yield traits may cause a decrease in the maternal ability of cows when they are selected for the direct weaning weight of the calf. The objective of this study was to analyse the genetic and environmental components of some traits of interest in beef cattle breeds managed in mountain conditions by analysing the actual cumulative milk yield at 150 days obtained by milking (MY150) and the weight at birth (BW), at 90 days (W90), at weaning (W150), and mature weight (MW). Genetic evaluations were conducted using field data from 2,679 calves born from 553 dams of Parda de Montaña beef cattle breed. The variances, genetic (both direct and maternal) and phenotypic, were estimated by a multi-trait animal model. Milk yield was correlated with maternal components of calf weight at 90 days and 150 days (genetic correlations of 0.59 and 0.48, respectively) and also correlated with a direct genetic component of W90 and W150 (genetic correlations of 0.58 and 0.54, respectively). The maternal heritability values for W90 and W150 were 0.023 (0.005) and

0.009 (0.004), respectively. The estimates of the direct-maternal genetic correlation for W90 and W150 were -0.13 (0.11) and -0.34 (0.16), respectively. Environmental effects, especially the sex of calf and dam parity for direct genetic effects and energy level of cow and body condition at calving for maternal effects, should be included in the evaluation models to obtain a proper estimation of genetic parameters for beef cattle evaluation. Genetic milk yield explains half the variation of maternal effects for W90 and W150. The prediction of milk yield will be better using maternal effects at 90 days than at 150 days. The combined index (maternal and direct) for the trait weight at 150 days yielded the highest economic response increasing the direct effect indirectly without decreasing the maternal effect at 150 days.

Keywords: Parda de Montaña**,** milk quantity, preweaning growth, maternal heritability, mature weight.

1. Introduction

In suckler cattle production systems, the weaning weight of the calves is the main source of farm income (Åby et al., 2012). Consequently, it is included as a selection criteria in most beef cattle selection schemes. At the genetic level, weaning weight depends on both the genetic potential of the calf (direct effect) and the effect of the dam (maternal effect). The most important maternal effects influencing calf growth from conception until weaning are the uterine environment during pregnancy, the transfer of antibodies through colostrum, the maternal ability of the cow to protect the calf, and the milk yield (Quintanilla and Piedrafita, 2000).

Most breeding programmes in beef cattle include direct and maternal effects in the evaluation model of weaning weight. Selecting for direct or maternal genetic values will have consequences on correlated traits depending on the correlation between different components and traits. Miller and Wilton (1999) found a negative correlation between the maternal environment of the dam and the genetic value of her calf. The negative genetic correlation (r_g) between direct and maternal genetic effects may indicate the antagonistic effects of genes related to growth and maternal ability (Lopes et al., 2013).

Selection for weaning weight may have unintended consequences. Although cow milk yield is phenotypically significantly correlated with calf weaning weight at different weaning ages (MacNeil and Mott, 2006), the genetic correlation between both traits can be negative (McHugh et al., 2014). This antagonism may cause a decrease in the maternal ability of cows if weaning weight is considered as the only selection criterion (Miller and Wilton, 1999). However, reliable data on cow milk yield are rare in beef breeds because they are not usually milked, and this trait is only indirectly estimated from calf growth rates (Liu et al., 2015), which are also associated with other aspects such as health or management.

Calf growth in extensive beef cattle systems, especially when based on rangelands or dry mountain areas, may be even more dependent on dam milk in some periods due to the low forage availability, pasture quality, and the unfeasibility of calf supplementation.

The objective of this study was to analyse the genetic and environmental component of selected traits in a beef cattle breed managed in mountain conditions. We analysed calf birth and weaning weights and their correlation with actual milk yield of their dams and with other traits such as weight at 90 days of age and mature weight.

2. Materials and methods

2.1 Animals and management

Data were collected at the La Garcipollera Research Station (Spain, 42° 37′ N; 0° 30′ W; 945 m above sea level), in the mountain area of the Southern Pyrenees (Spain), over 17 years (1989-2012) in Parda de Montaña beef cattle breed. This breed is a suckler cattle breed that is widespread throughout northern Spain and that came from the ancient Brown

Swiss and its crosses with local breeds. It has been used as a dual purpose milk-beef breed (Álvarez-Rodríguez et al., 2010), but in the past few decades, it has been selected for only beef production and mothering abilities (calving ease and weaning weight). The maturing rate of this breed is considered intermediate between highly specialized (late-maturing beef breeds) and low meat producers (early-maturing hardy breeds) (Albertí et al., 2005). The management of the experimental herd of Parda de Montaña cattle consisted of housing during the winter, grazing on high mountain pastures (1500-2200 m above sea level) during the summer and grazing on valley meadows and forest pastures (945-1500 m above sea level) during the spring and autumn. For reproductive management, the age at first calving ranged from 2 to 4 years in the database. There were two calving seasons, spring (March to May) and autumn (September to November). The calves were raised either with free access to their dams (Free) or with restricted access (Restricted) twice a day for approximately 30 minutes each (Álvarez-Rodríguez et al., 2010). Depending on the trial, the calves did or did not receive concentrates *ad libitum* during the suckling phase (concentrate supplementation). The calves were weaned at around five (autumn-born calves) or six months of age (spring-born calves) (Villalba et al., 2000). Further details of management can be found in Casasús et al. (2002).

2.2 Data collection and categorization

The database was constructed with records registered from 2,679 calves born from 553 dams (Table 1). Data come both from usual records of farm (BW, W150) and from records obtained in controlled trials (W90, MY150, MW). A pedigree with 4,307 animals was used, of which 311 belonged to the base population. Calf birth weight (BW) was recorded in the first 24 hours after birth. Weight at 90 days of age (W90) was calculated by linear regression of weights recorded from birth to 105 days (3 to 6 records per calf), and weight at 150 days, considered as weaning weight, was calculated by linear regression of data recorded from 105 to 165 days (5 to 11 records per calf). Mature weight (MW), recorded only for females, was the weight of 8-year old adult cows estimated from a B-spline function including three internal knots located at 365, 700, and 1,000 days of age, and two external knots located at 0 and 3,000 d with random regression coefficients in each knot (Cano et al. ,2016).

The dam milk yield was estimated by mechanical milking with oxytocin injection, according to the technique of Le Du et al. (1979). Between two and five daily records per lactation were used to estimate the accumulated milk yield at 150 days (MY150) using the method of Fleischmann (ICAR, 2014).

All cows with milk yield recorded were scored for body condition at calving (BCS), based on the scale from 0 to 5 of Lowman et al. (1976), and classified according to terciles into three BCS classes (low <2.43, medium 2.44-2.61, or high >2.62). The dietary energy supply during the lactation phase was available on a pen basis, and the cows were classified into three classes according to energy intake terciles: low <102 MJ of metabolizable energy, medium 103-109 MJ, and high >110 MJ.

2.3 Statistical Analyses

Preliminary analyses were carried out to determine the significance of the fixed environmental effects, which were later included in the model on all studied variables using the GLM procedure of SAS® software (SAS Inst. Inc., Cary, NC). For the weight traits (BW, W90, W150, MW), the effects of calf sex, dam parity, the age of dam at first calving, and year-season were evaluated. In the case of dam milk yield (MY150), the significance of the aforementioned effects and that of calf suckling management and calf concentrate supplementation were examined.

The variance components and genetic and phenotypic parameters were estimated using the software VCE6 (Groeneveld et al., 2010) by a multi-trait animal model. The random animal effects considered in the model were d_{BW}, d_{W90}, d_{W150}, m_{BW}, m_{W90}, m_{W150}, d_{MY150}, and d_{MW}. The d_{BW}, d_{W90}, and d_{W150} were the calves' contributions to BW, W90, and W150, respectively, of their genetic potential for growth often referred to as direct effects. The $m_{BW,}$ m_{W90}, and m_{W150} were the genetic components of the environment that the dam provided for calf BW, W90, and W150 weights, respectively, often referred to as maternal effects. Finally, d_{MY150} and d_{MW} were the animal genetic potential for milk yield and mature weight, respectively.

For each trait, the model included the random animal effects, the environmental fixed effects and the residual effects. The model used for the weight traits (BW, W90, W150, MW) can be represented as:

$$y_{ijklmn} = \mu + S_i + O_j + A_k + YS_l + d_m + m_n + PE_n + e_{ijklmn}$$

where y_{ijklmn}= studied weight trait, μ = overall mean, S_i= sex effect (Female, Male), O_j= dam parity effect (1, 2, >2), A_k= age (years) at first calving effect (<2.5, 2.5-3, >3), YS_l= year-season random effect, d_m= additive genetic effect of the calf associated with observation y_{ijklmn}, m_n= additive genetic effect of the dam associated with observation y_{ijklmn}, PE_n= permanent environment effect of dam associated with observation y_{ijklmn}, e_{ijklmn}= residual effect.

The model used for the milk yield (MY150) can be represented as:

$$y_{ijklmnop} = \mu + S_i + C_j + M_k + O_l + CxE_m + A_n + YS_o + d_p + PE_p + e_{ijklmnop}$$

where $y_{ijklmnop}$= MY150, μ= overall mean, S_i= calf sex effect, C_j= calf concentrate supplementation effect (Yes, No), M_k= calf suckling management effect (Free, Restricted), O_l= parity effect, CxE_m= interaction between cow body condition and cow dietary energy intake effect, A_n= age at first calving effect, YS_o= year-season random effect, d_p= additive genetic effect of the cow associated with observation $y_{ijklmnop}$, PE_p=

permanent environment effect of dam associated with observation, $e_{ijklmnop}$= residual effect.

The variance-covariance matrix (G) used was as follows, where A is the pedigree matrix:

$$G = \sigma^2 \begin{bmatrix} u_{BW} \\ u_{W90} \\ u_{W150} \\ u_{MW} \\ u_{MY150} \\ u_{W90m} \\ u_{W150m} \end{bmatrix} = \begin{bmatrix} \sigma^2_{BW} & \sigma_{u_{BW},u_{W90}} & \sigma_{u_{BW},u_{W150}} & \sigma_{u_{BW},u_{MW}} & \sigma_{u_{BW},u_{MY150}} & \sigma_{u_{BW},u_{BWm}} & \sigma_{u_{BW},u_{W90m}} & \sigma_{u_{BW},u_{W150m}} \\ & \sigma^2_{W90} & \sigma_{u_{W90},u_{W150}} & \sigma_{u_{W90},u_{MW}} & \sigma_{u_{W90},u_{MY150}} & \sigma_{u_{W90},u_{BWm}} & \sigma_{u_{W90},u_{W90m}} & \sigma_{u_{W90},u_{W150m}} \\ & & \sigma^2_{W150} & \sigma_{u_{W150},u_{MW}} & \sigma_{u_{W150},u_{MY150}} & \sigma_{u_{W150},u_{BWm.}} & \sigma_{u_{W150},u_{W90m}} & \sigma_{u_{W150},u_{W150m}} \\ & & & \sigma^2_{MW} & \sigma_{u_{MW},u_{MY150}} & \sigma_{u_{MW},u_{BWm}} & \sigma_{u_{MW},u_{W90m}} & \sigma_{u_{MW},u_{W150m}} \\ & & & & \sigma^2_{MY150} & \sigma_{u_{MY150},u_{BWm}} & \sigma_{u_{MY150},u_{W90m}} & \sigma_{u_{MY150},u_{W150m}} \\ & & & & & \sigma^2_{BWm} & \sigma_{u_{BWm},u_{W90m}} & \sigma_{u_{BWm},u_{W150m}} \\ & & & & & & \sigma^2_{W90m} & \sigma_{u_{W90m},u_{W150m}} \\ sim. & & & & & & & \sigma^2_{W150m} \end{bmatrix} \otimes A$$

Estimated marginal means obtained from the solution of the model for fixed effect levels were compared with a t-test with a significance level of 5%.

We defined weaning weight at 150 days (actual age at weaning of farms) as the selection goal. Different scenarios of index of selection, based on phenotypic weights at 90 and 150 days of age, and considering direct and/or maternal effects were calculated according to Van Vleck (1970). The correlated response was obtained based on the estimated co-variance matrix.

3. Results and discussion

3.1 Environmental effects

The estimates of fixed effects for calf weight traits and dam milk yield are presented in Table 2 and Table 3, respectively. All the weight traits were affected by calf sex and parity of the dam ($P< 0.05$); however, no differences were found among the different categories of cow's age at first calving ($P> 0.05$). Males were heavier than females throughout lactation, as their birth weight was 2.8 kg higher ($P=0.035$), and they differed by 5.4 kg at 90 days ($P=0.002$), and by 8.4 kg at 150 days ($P=0.028$). Similarly, Fina et al. (2013)

found higher birth weights in males of Bruna dels Pirineus breed, and Fries and Ruvinsky (1999) reported a sex influence on birth weight and W150 in beef cattle breeds.

Calves born from cows with more than two calving events had higher BW, W150, and MW than calves from first- and second-calving cows ($P<0.05$). Calves born from primiparous cows reached a lower MW than calves from second-calving cows, but their BW did not differ, although the calving ease was lower in the first-calving cows of this breed (Cortés-Lacruz et al., 2016). Goldberg and Ravagnolo (2015) have also found an effect of age of dam (i.e., parity) on the postweaning weights of their calves. In our study, the age of the dam at first calving did not affect the BW, W90, W150, and MW of the calves produced during her lifetime.

The dam milk yield was estimated as the accumulated production during lactation, and the individual monthly data were not considered separately, because Cortés et al. (2015) obtained high correlations (>0.86) between monthly milk yield traits during the first 5 months of lactation. The MY150 was not influenced by calf sex, suckling management or concentrate supplementation, but it differed significantly depending on the parity and the age of the cow at first calving.

Calf supplementation did not affect MY150 of the cows, which suggests that concentrate consumption in beef calves is not sufficient to alter their suckling behaviour; therefore, it does not affect the milk production of their dams (Barros et al., 2015). In the current study, calf suckling management did not affect the milk yield, similar to previous studies conducted in the same condition in this breed (Sanz et al., 2003). However, Quintans et al. (2010) reported that increased the suckling frequency in calves with free access to their dams resulted in increased milk yield. Calf sex did not affect the milk yield, which corroborates with the results observed by Forster et al. (2010) in Aberdeen Angus cows. However, these results were contrary to those of Albertini et al. (2012) in Angus breed, who reported higher milk intake and suckling frequency in male beef calves. Robison et al. (1978) concluded that the milk yield of beef cows was influenced more by calf size than by calf sex.

The parity affected MY150 ($P<0.05$), which was higher in multiparous than in primiparous cows, with the values of second-calving cows being intermediate. Likewise, Pimentel et al. (2006) reported lower milk yields in Hereford primiparous than in multiparous cows. These results are caused by large metabolic differences in primiparous and multiparous cows, as the former require nutrients for their continued growth, which cannot be invested in milk production (Wathes et al., 2007). Neville et al. (1974) reported that calves born from cows older than 5 years received more milk and were heavier at weaning than those born from younger cows in Hereford breed. The age at first calving affected MY150, which was higher in 3-year-old than in 2.5-year-old primiparous cows. This was in agreement with Kratochvilova (2001), who reported lower milk production in cows that calved for the first time at two years of age than when they were older than three years.

Figure 1 shows the results of MY150 in relation to BCS at calving and dietary energy intake during lactation. Both BCS and a high dietary energy intake affected milk production. Energy intake seemed to have more impact than BCS at calving on milk yield. For cows with a medium energy intake, the loss in MY (from high to low BCS) was 160 kg (13% of the mean), whereas for cows with medium BCS, the loss in MY (from high to low energy intake) was 290 kg (23% of the mean). These results concur with those obtained by McParland et al. (2015) in dairy cattle. Conversely, BCS and energy level had no effect on milk yield measured by the weigh-suckle-weigh method in Charolais cows (De La Torre et al., 2015). The body condition score ranges could be very different between observers making it difficult to compare between experiments. Nevertheless, Sanz et al. (2004) reported relevant effects of similar BCS classes on reproduction traits within the same database in Parda de Montaña breed. The effect of diet and BCS on milk yield could also be modulated by the adaptive abilities of cows to allocate energy to different functions, which could depend on breed and milk potential.

3.2 Direct and maternal genetic effects.

Table 4 presents the heritability estimates of the direct and maternal additive genetic effects for all traits and their correlation. The heritability of direct BW was high compared with the results from Fina et al. (2013) in Bruna dels Pirineus beef cattle breed (0.30). The estimates of heritability for W90 and W150 were low compared with Morales et al. (2013), who reported values of 0.37 and 0.58 for heritability of W120 and W180, respectively, in the Retinta breed.

Maternal heritability estimate for BW was high compared with Mujibi and Crews (2009) in Charolais breed (0.14). Maternal heritability estimate was lower for W150 than for W90. These estimates were lower than results from Morales et al. (2013) and confirms that the dependence of calf growth on maternal effects, especially dam milk, decreases as animal age increases.

The estimates of heritability for MY150 were low compared with MacNeil and Mott (2006) in Hereford breed. The heritability for MW was lower than the estimates obtained by Meyer (1995) (0.47) in Hereford breed. Nonetheless, the estimation of heritability for MW in this study should be treated carefully, because it comes from experimental herd where cows were subjected to extreme nutritional managements in some of the trials. Moreover, the environmental effect was probably higher than in commercial farms.

The correlations between direct and maternal effects estimated in this study for BW, W90, and W150 were 0.23, -0.13, and -0.34, respectively. These results were contrary for BW compared with Mujibi and Crews (2009) (-0.27), but for W90 and W150, they were similar to results from other studies conducted with similar beef cattle breeds, with a correlation of -0.34 in Bruna dels Pirineus (Quintanilla et al., 1999).

Meyer (1997) reported that the estimation of covariance components of maternal effects is complex because direct and maternal effects can be confounded. In the same direction, the estimation is highly model dependent. In our data, when some of the fixed environmental effects were not included in the model, the genetic correlation between direct and maternal effects was positive (results not shown).

3.3 Genetic and phenotypic correlations

Table 5 presents the genetic and residual correlations among the direct and maternal effects of all traits. The estimates of the genetic correlations of BW with W90 and W150 were in the range of literature estimates. Vargas et al. (2014) reported direct genetic effect correlation for birth weight and weaning weight of 0.57 in Colombian multibreed beef cattle population. The estimates of the BW and MY genetic correlation was 0.30, which was contrary to the reported results of Lee and Pollak (2002) in Korean beef cattle (-0.09). The estimates of the genetic correlation between BW and MW was moderately high and positive and higher than the value (0.35) reported by Berry and Crowley (2013). For maternal effects, the estimates of genetic correlations between BW and W90m, and BW and W150m were negative although minuscule, which was in agreement with the results of Pedrosa et al. (2014) for birth weight and maternal weaning weight effect (-0.13).

The genetic correlation for direct effects of milk yield (MY150) and weaning weight (W150) were moderate and positive. Lee and Pollak (2002) in Korean beef cattle breeds and Miller and Wilton (1999) in multibreed beef cattle have been reported negative and very low correlations. The genetic correlation for W90 and W150 and BWm were similar than results obtained by Gutiérrez et al. (2007).The genetic correlations of weights in early life (W90 and W150) with mature weight (MW), 0.81 and 0.83, respectively, were similar to the estimates of Meyer (1995) (0.66) in the Hereford breed between weaning weight and mature weight. This result may be attributed to the fact that the MW of this study is an estimate from the cow growth curve; therefore, some environmental effects have not been considered in this theoretical function. The estimates of the genetic correlation between MY150 and MW (0.22) were similar to those observed by Liinamo et al. (2001) (0.15) in Finnish Ayshire cattle.

The genetic correlations between milk (MY150) and maternal effects on weights were positive and moderate. In a multibreed beef cattle herd, Miller and Wilton (1999) and MacNeil and Mott (2006) obtained high genetic correlations of 0.76 and 0.80, respectively, between both variables. Their results indicate that maternal weight effect genetic values are good predictor of a cow’s potential for milk yield. The estimates of genetic correlation for W90 and W150 were similar to those obtained by Morales et al. (2013) (0.80) in the Retinta breed. The estimates of W90m and W150m were similar to those obtained by Morales et al. (2013) (0.88) for the genetic correlation between W120m and W180m. The estimates of genetic correlations between BWm and W90m and W150m were low compared with those observed by Gutiérrez et al. (2007) between maternal birth weight and maternal weaning weight (0.24) in Asturiana de los Valles breed.

The permanent environmental (c^2) effects for BW, W90, W150, and MY150 were 0.080 (0.010), 0.061 (0.010), 0.050 (0.008), and 0.018 (0.011), respectively. These results for W90 and W150 were similar to results reported by Quintanilla et al. (1999) for weaning weight (0.047). Estimate of repeatability for MY150 (0.14) was lower than results reported by MacNeil and Mott (2006) (0.39).

Incomes of Parda de Montaña producers are derived from the price of calves at weaning. Because the genetic correlations between the direct and maternal effects obtained in this breed are negative for weaning weight, the models of evaluation should include both direct and maternal effects. However, selection could be based only on direct or maternal genetic effects or on an index combining direct and maternal effects. In addition, selection could be based on weights at the early age of calves (i.e., W90) or on weights registered close to the age of actual weaning (i.e., W150). Early weights were more related with dam milk yield because the concentrate and forage consumption by the calf was very low (Blanco et al., 2008). However, in the late ages, it is more important to consider the growth capacity of the calf based on forage and concentrate consumption. In fact, in our results, the maternal genetic effect of W90m was more related with milk yield than the maternal genetic effect of W150m was.

Table 6 presents the correlated response, based on the estimated co-variance matrix, when selection criteria were weaning weight at 90 or 150 days of age, using either direct, maternal, or direct and maternal genetic values. We assumed the same economic weight for direct and maternal genetic values for weaning weight at 150 days. Under this hypothesis, the combined index (maternal and direct) for the trait weight at 150 days yielded the highest economic response. This result could change with different economic weights (i.e depending on the cost of maternal feeding, or the use and cost of feed supplementation to calves) and with the inclusion of other traits in the index (i.e. mature weight to account for incomes from mature weight).

Selecting for the direct effect at 150 days or for a combination of maternal and direct effects at 150 days had similar economic responses, but the first strategy increased the response via increasing the direct effect, with a decrease in maternal effect and milk production of cows, whereas the second strategy increased the maternal effects and milk yield of cows.

The correlated response in the milk production of cows seemed to increase the selection strategy. However, selection of the direct effect at 150 days had a low response for milk yield, which combined with the reduction of the expected maternal effect would probably lead to problems in the maternal ability of the cows in the next generation. Sepchat et al. (2015) showed an overall decline in milk production, in the last 40 years, in the Limousin and Salers breeds. This decline in production could be explained by the selection for slaughter performance because the cows increased their average size from 5 to 6 kg / year. Finally, the selection strategies including direct weights showed a high response in the mature weight. The relation of mature weight with maturity, long and short time productivity of cows and feeding costs are still under discussion. Regatieri et al. (2012) recommended that mature live weight be considered in genetic evaluations to maintain a suitable cow size for a given production system. High mature weight involves increased nutritional requirements (Jenkins and Ferrell, 1994), thus reducing the production efficiency (Silva et al., 2015). In addition, when selection for beef production results in a higher adult weight, the heifers tend to reach puberty at an older age and at a heavier weight relative to mature BW than breeds selected solely for milk production (Ferrell, 1982). Depending on the economic value assigned to this trait, the index combining direct and maternal effects could change, giving more importance to maternal than the direct effect.

Conclusions

Environmental effects, especially the sex of the calf and the dam number for calving (for direct genetic effects), and the energy level of the cow and its body condition at calving (for maternal effects) should be included in the models of evaluation to obtain proper estimations of genetic parameters for beef cattle evaluation.

Genetic milk yield explains half the variation of maternal effects for W90 and W150. The prediction of milk yield will be better using maternal effects at 90 days than at 150 days. The combined index (maternal and direct) for the trait weight at 150 days yielded the highest economic response increasing the direct effect indirectly without decreasing the maternal effect at 150 days.

Conflict of interest statement

The authors declare that they have no conflict of interest.

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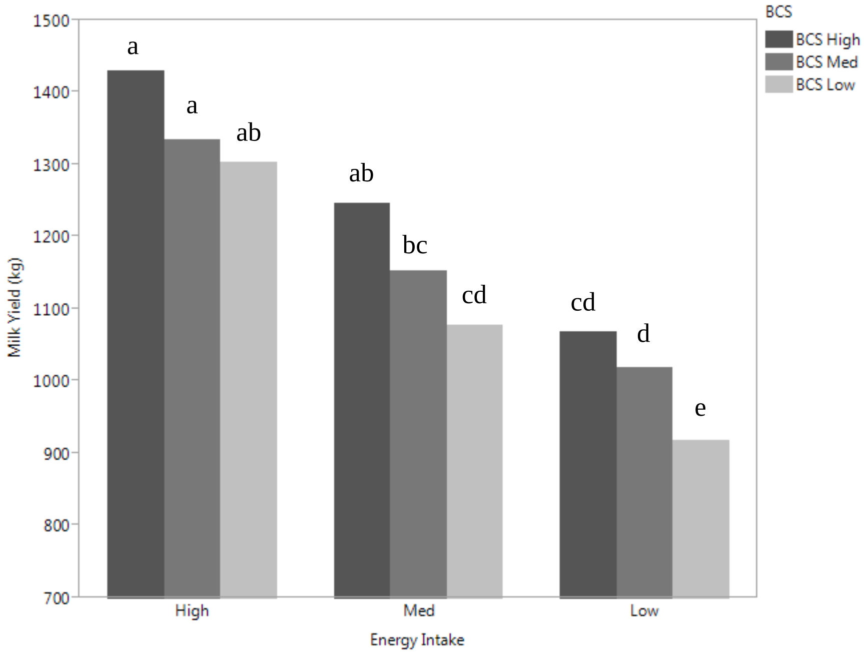

Figure 1

Accumulated milk yield during lactation (MY150) according to dietary energy intake and body condition score (BCS) at calving.

Estimates with the same superscript did not differ significantly (P< 0.05).

Table 1

Descriptive statistics for calf birth weight (BW), weight at day 90 (W90), weaning weight (W150), cow mature weight (MW) and accumulated dam milk yield at 150 days (MY150).

	Traits				
	BW	W90	W150	MW	MY150
Nº of records	2516	609	2253	1455	529
Nº of cows with progeny records	448	218	321	346	147
Nº of sires with progeny records	123	62	90	105	65
Mean (kg)	42.4	121	169	618	1226
Standard deviation (kg)	6.82	18.1	27.9	36.5	340.2

Table 2

Fixed effects estimates and standard error in parentheses for birth weight (BW), weight at 90 days (W90), weaning weight (W150) and mature weight (MW).

Effect	Level	BW	W90	W150	MW[1]
Sex	Female	42.1 (0.39)[b]	117.8 (1.37)[b]	166.7 (1.70)[b]	-
	Male	44.9 (0.37)[a]	123.2 (1.28)[a]	175.1 (1.59)[a]	-
Dam parity	1	42.1 (0.36)[b]	115.3 (2.49)[b]	167.1 (1.81)[b]	602 (2.6)[c]
	2	43.1 (0.35)[b]	118.9 (1.61)[b]	171.8 (1.54)[ab]	613 (2.8)[b]
	>2	45.5 (0.10)[a]	123.2 (1.27)[a]	173.9 (0.43)[a]	625 (1.8)[a]
Age at first calving	<2.5	41.4 (0.8)	121.4 (3.1)	167.2 (5.4)	606 (9.1)
	2.5-3	41.8 (0.7)	122.7 (2.8)	174.9 (4.8)	609 (7.6)
	>3	42.5 (0.5)	131.0 (2.0)	168.9 (3.3)	618 (8.6)

[1]Only females in MW analysis

Estimates with the same superscript within trait and effect did not differ significantly (P< 0.05).

Table 3

Fixed effects estimates and standard error in parentheses for milk yield at 150 days (MY150).

Effect	Level	MY150 (kg)
Calf sex	Female	1143 (29)
	Male	1164 (16)
Calf concentrate supplementation	No	1143 (12)
	Yes	1163 (39)
Calf suckling management	Free	1165 (33)
	Restricted	1141 (13)
Parity	1	1005 (66)[b]
	2	1142 (58)[ab]
	>2	1312 (52)[a]
Age at first calving	<2.5	1131 (8)[b]
	2.5-3	1151 (7)[ab]
	>3	1162 (8)[a]

Estimates with the same superscript within effect did not differ significantly ($P < 0.05$).

Table 4

Parameter estimates and standard error in parentheses for calf birth weight (BW), weight at 90 days (W90), weaning weight (W150), cow mature weight (MW) and dam milk yield at 150 days (MY150).

Trait	h^2	m^2	$r\ (d,m)$
BW	0.46 (0.02)	0.005 (0.002)	0.23 (0.23)
W90	0.25 (0.02)	0.023 (0.005)	-0.13 (0.11)
W150	0.15 (0.01)	0.009 (0.004)	-0.34 (0.16)
MW	0.22 (0.01)	-	-
MY150	0.12 (0.02)	-	-

h^2 = direct heritability; m^2 = maternal heritability; $r\ (d,m)$ = correlation between direct and maternal genetic effects.

Table 5

Direct genetic correlations (above diagonal) and residual correlations (below diagonal) with standard error in parentheses for birth weight (BW), weight at 90 days (W90), weaning weight (W150), milk yield at 150 days (MY150), mature weight (MW), maternal weight at 90 days ($W90_m$) and maternal weaning weight ($W150_m$).

Trait	BW	W90	W150	MW	MY150	BW_m	$W90_m$	$W150_m$
BW		0.30 (0.03)	0.26 (0.04)	0.60 (0.04)	0.30 (0.08)	0.23 (0.23)	-0.16 (0.12)	-0.13 (0.18)
W90	0.56 (0.02)		0.97 (0.01)	0.81 (0.03)	0.58 (0.05)	-0.12 (0.27)	-0.13 (0.11)	-0.20 (0.17)
W150	0.30 (0.02)	0.72 (0.02)		0.83 (0.03)	0.54 (0.06)	-0.32 (0.27)	-0.24 (0.12)	-0.34 (0.16)
MW	0.10 (0.02)	0.27 (0.02)	0.22 (0.02)		0.22 (0.06)	-0.30 (0.23)	-0.58 (0.11)	-0.61 (0.15)
MY150	-0.28 (0.04)	-0.15 (0.03)	-0.08 (0.02)	0.09 (0.03)		0.25 (0.41)	0.59 (0.12)	0.48 (0.22)
BW_m							0.69 (0.17)	0.80 (0.19)
$W90_m$								0.98 (0.05)

Table 6

Correlated response expected (per unit of selection intensity) after selection of weaning weight based on phenotypic weights at 90 or 150 days of age.

	Phenotipic value used					
	Weight at 150 day			Weight at 90 day		
Trait (in kg)	Direct	Maternal	Direct and maternal	Direct	Maternal	Direct and maternal
Direct W90	1.05	-0.11	0.94	4.50	-0.11	4.39
Direct W150	4.05	-0.21	3.84	1.57	-0.12	1.45
Milk Yield 150d	2.27	0.49	2.76	3.15	0.97	4.12
Maternal W90	-0.08	0.16	0.08	-0.11	0.41	0.31
Maternal W150	-0.21	0.24	0.03	-0.16	0.24	0.08
Mature weight	1.33	-0.24	1.09	1.68	-0.36	1.31
Economic[1]	11.52	0.10	11.61	4.22	0.36	4.59

[1] Assuming equal economic value (3€/kg) of direct and maternal values.